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SURVEY - MONOMETHYLHYDRAZINE PROPELLANT/MATERIAL COMPATIBILITY

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JULY 1977

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FOREWORD

The work reported herein is sponsored by the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California, under Military Interdepartmental Purchase Request, Project Order Number F04611-77-X-0002. The program is being administered under the Technical Direction of Lt. W. T. Leyden (AFRPL/LKDP).

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A compilation of data describing monomethylhydrazine (MMH) specification grade propellant and material compatibility has been prepared based upon available information from literature searches. Materials include aluminum alloys and corrosion-resistant steels. Maximum temperature was 71°C (160°F).

Although few data are available, and most at the lower temperatures, it appears that, in general, monomethylhydrazine exhibits somewhat greater stability toward catalytic decomposition than does hydrazine (Hz) propellant.

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It is also generally considered that metals which are compatible with hydrazine are compatible with monomethylhydrazine. Therefore, based upon similarity and comparison, it is not apparent that incompatibilities will be experienced with pure monomethylhydrazine and metals of interest up to a temperature of 43°C (110°F).

However, no data are available on the conjoint effects of acidic contaminants, carbon dioxide and water. Hence, no predictions of the effects of these contaminants can be made with confidence.

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I. INTRODUCTION

A. Discussion

Propellant/material compatibility data are needed for alternate structural alloys suitable for shipping and storage containers for monomethylhydrazine (MMH) propellant (Table 1) (Ref. 1). At the present time the Department of Transportation (DOT) has authorized only corrosion-resistant steel (CRES) types 304 and 347 for tanks and drums for MMH service (Refs. 2 and 3). The capacity of available shipping equipment and storage facilities will be taxed based upon the MMH propellant ready supply and usage requirements forecast for the NASA Space Shuttle Program.

The use of other materials such as aluminum alloys and CRES types must be considered for these applications.

B. Objective

The objective of this program is to demonstrate the compatibility of MMH propellant with several specified alloys that meet the requirements of DOT shipping specifications.

C. Scope

The overall program consists of three phases:

Phase 1 - compatibility data compilation
Phase 2 - compatibility determinations
Phase 3 - documentation (final report)

The scope of work presented in this report covers Phase 1, i.e., the literature survey and results.

II. COMPATIBILITY DATA COMPILATION

A. Survey

A literature survey was conducted to identify pertinent or related data for MMH propellant and material compatibility. The period covered was from 1960 to the present. Primary sources of information included:

Government agencies (NASA, DOD)
Industry contractors (documentation)

Document and information acquisition centers (CPIA)
Open literature (Chemical Abstracts)
Meetings (JANNAF, AIAA)

Further details covering this aspect are presented in the Appendix of this report.

B. Requirements

Specific requirements relative to propellant conditions and material selections for aluminum alloys and corrosion-resistant steel types were used for determining applicability of reported information and/or data.

1. Propellant

The requirements for the monomethylhydrazine (MMH) are delineated in Table 2.

2. Materials

The various materials of construction considered are listed in Table 3. Chemical compositions and mechanical properties in accordance with American Society for Testing and Materials, Specifications ASTM B209-74 (Ref. 4) and ASTM A240-75a (Ref. 5), are indicated in Tables 4 and 5.

In addition to the above requirements, special emphasis was placed upon identification of any deleterious effects that were observed during testing or posttest examinations. Postulations derived from directly related programs were also considered.

The following sections present the results of the literature review. Information sources were References 1 through 25.

III. CHEMICAL AND PHYSICAL PROPERTIES

Monomethylhydrazine (MMH) is a clear, colorless liquid with a strong ammoniacal odor (Refs. 6 to 8). It is more volatile and more toxic (a maximum allowable concentration of 0.35 mg/m^3 has been established (Ref. 9)) than hydrazine and poses a greater explosion and fire hazard than hydrazine because of its low flash point (1°C), Table 6.

MMH is stable up to its boiling point when kept out of contact with air. Because of its reactivity with oxygen, and the fact that it absorbs CO_2 and moisture from the air, MMH should be handled under a blanket of nitrogen gas.

Like hydrazine, MMH is not sensitive to impact or friction, and is superior to hydrazine in thermal stability. It is sensitive to catalytic decomposition by the same metals which cause decomposition of hydrazine. Because the chemical properties of MMH are similar to those of hydrazine, and it has a slightly lower reactivity, it is generally considered that metals which are compatible with hydrazine will also be compatible with MMH (Refs. 6, 10-12).

IV. DECOMPOSITION OF MMH

Relatively little data are available on the products of the liquid phase or catalytic decomposition of MMH. Information on the products of reaction and the kinetics of decomposition are of interest in order to predict the rate of pressure increase in closed systems.

A. Thermal Decomposition

Axworthy et al. (Ref. 13) investigated the thermal decomposition of liquid MMH at 200°C and found that the major products of decomposition are ammonia, monomethylamine, azomethane, nitrogen and methane, plus an unidentified species. Hydrogen is found only in trace amounts.

The stoichiometry based on gaseous products is:

$$CH_3NH\ NH_2 \longrightarrow 0.48\ NH_3 + 0.37\ CH_3NH_2 + 0.24\ (CH_3N)_2 + 0.21\ N_2 + 0.15\ CH_4 + 0.004\ H_2$$

The investigation showed further that the decomposition rate of MMH in Pyrex glass is only one-tenth the rate observed with hydrazine. The presence of a 321 CRES surface increased the decomposition rate of propellant-grade MMH by a factor of 5.

Stanford Research (Ref. 14) investigated the presence of various substances (including metal salts) in specification grade and refined grade MMH to provide an understanding of the factors influencing its stability. MMH heated in Pyrex glass tubes at 175°C yielded the products CH_4, N_2, H_2, NH_3, CH_3NH_2, and $(CH_3)_2\ N_2$. Only a trace of H_2 was formed at temperatures below 130°C. Care was taken to exclude CO_2 from all container tubes. Small amounts (0.003M) of dissolved nickel and iron increased the decomposition rate of MMH by a factor of 10 at 100°C. Dissolved copper had no appreciable effect. The addition of 1% water to MMH had no effect on its decomposition rate at 175°C.

B. Effects of Contaminants (CO_2 and H_2O)

Of even greater interest to the present investigation is the reported effect of acid-forming materials on the decomposition of MMH. Additions of acid-forming materials such as NH_4Cl, HCl, NH_4NO_3, or CO_2 have been shown to strongly accelerate the decomposition of hydrazine in the presence of metals (Ref. 15). Although similar studies apparently have not been made with MMH, the investigation reported in Ref. 13 found that the addition of 1 percent NH_4Cl increased the rate of MMH decomposition at 200°C in Pyrex by a factor of 100 - a more pronounced effect than that observed with hydrazine. The effects of metal surfaces were not investigated. It appears probable, however, that acidic impurities or contaminants will be detrimental to the stability of MMH in contact with some metal surfaces.

C. Catalytic Decomposition

Rocketdyne (Ref. 13) reported that the volatile products of the decomposition of MMH over Girdler 6-22, Englehard MFSA-4A, and Shell 405 catalysts were predominantly CH_4 and N_2, with only trace amounts of H_2 and C_2H_6. Products not volatile at -78°C, such as NH_3 and azomethane, would not have been identified in this study.

D. Decomposition in Contact with Metals

Aerojet (Ref. 16) investigated the compatibility of titanium, 347 CRES, 2014 T6 Al, 2024 Al, maraging steel A, and maraging steel B, with MMH at 70°C. After 107 days only the maraging steels gave any indication of instability. The criterion of compatibility was the development of significant pressure in the test capsule compared to the pressure development of controls which contained no metal specimen.

The maraging steels had the following compositions: maraging steel A - 18 Ni, 4 Mo, balance Fe; maraging steel B - 20 Ni, 1-1/2 Ti, balance Fe. In this case the lack of compatibility may in part be attributed to the presence of molybdenum and high nickel in the alloys. Molybdenum, and possibly nickel, are known to effect decomposition of hydrazine-type fuels (Ref. 17).

In the Aerojet compatibility investigation, the major volatile product of decomposition for all metals tested was N_2. No CH_4 was reported and only a trace of H_2 and NH_3 in one test. Methylamines and formaldehyde methylhydrazine were reported as decomposition products remaining in the liquid phase. The apparent absence of methane in these studies is surprising in view of its ubiquity in other decomposition reactions reported (Refs. 13, 14, 15, 18, and 19).

JPL reported on the decomposition of MMH stored in contact with 6Al-4V Ti, 303 CRES and 304L CRES at 43°C (Ref. 18). In contact with both 6Al-4V Ti and 303 CRES, MMH decomposition amounted to only 0.18 percent of the propellant weight in 1368 days. A slightly smaller (0.15%) decomposition was noted in contact with 304L CRES for 150 days. Approximately equivalent amounts of N_2 and CH_4 were found in the volatile products of decomposition.

E. Radiolytic Decomposition

Gamma irradiation of 100 cc of MMH (0.85×10^7 rads) produced 227 cc of gas at 250°C and 1 atmosphere consisting of nearly equal amounts of H_2, N_2, and CH_4. Free radical scavengers had no effect on decomposition, indicating a molecular or ionic decomposition reaction rather than a free radical mechanism (Ref. 19).

V. COMPATIBILITY OF MMH WITH METALS

A. General

A general review of published data has been made for the compatibility of MMH propellant as indicated in Table 2 and certain aluminum and CRES alloys given in Table 3.

It is frequently asserted that because the molecular structure of MMH is identical to hydrazine except that one hydrogen atom is replaced by a methyl group, MMH may be expected to have chemical characteristics and corrosivity toward metals similar to hydrazine. This attitude probably accounts for the paucity of MMH compatibility data to be found in the literature. In fairness to the proponents of the philosophy mentioned above, it should be pointed out that no data are known that refute it. Extensive comparative data simply do not exist.

B. Aluminum Alloys

Martin Marietta (Refs. 10, 20) rated 1100-0, 2014-T6, and 2219-T87 compatible with MMH for 300 hours at 135°C, no corrosion or MMH decomposition.

TRW (Ref. 21) indicated that the following aluminum alloys are fully compatible with MMH at 71°C or below for short term use (2 weeks): 5052, 5154 and 6061.

Aerojet propellant material compatibility tests at high temperatures (Ref. 22) showed exothermic reaction of 2014-T6 and 6061-T6 alloys with MMH at temperatures in the 385-390°C range — lower than observed with CRES alloys. No relationship with compatibility at lower temperatures should be inferred.

Stanford Research (Ref. 14) reported that heating MMH to 100°C for 7 days in contact with the following alloys showed no increase in decomposition of propellant and no noticeable corrosion of the metal surfaces. The metals were aluminum alloys 1100, 2014, 6061; corrosion-resistant steels types 321, 347, 17-7; and Inconel X-750.

C. CRES Alloys

Piccirillo (Ref. 23) reported MMH to be compatible with 347 and A286 stainless steel for 6 months at 65°C. No corrosion effects were observed.

Martin Marietta (Ref. 10) rated the following CRES alloys as "probably compatible for short term use" (temperature not specified): 303, 304, 321, 17-7 PH.

Aerojet (Ref. 22) investigated the stability of hydrazine-type fuels when heated in contact with 11 different metallic materials, including the following CRES alloys: 304L, 316, 321, 347, and 17-7 PH. With the CRES alloys, exothermic reaction began at about 430° - 460°C, apparently indicating a self-sustaining decomposition reaction. No relationship to compatibility at lower temperatures can be inferred, however.

JPL (Ref. 18) reported no significant corrosion or propellant decomposition with 303 CRES in contact with MMH for 1368 days at 43°C or with 304L CRES in 130 days at 43°C. Corrosion was limited to faint tarnishing of the specimens. Approximately ten other test specimens (303, 304L, 316, 347) are still undergoing testing, and after six years exposure to MMH at 43°C, no serious corrosion or propellant decomposition effects are noticeable.

TRW (Ref. 21) indicates that the following CRES alloys are fully compatible with MMH at 71°C or below for the short term use (2 weeks): 304, 321 and 17-7 PH.

Boeing (Ref. 24) reported specification grade MMH to be compatible with 304L CRES for exposure periods up to 60 days at temperatures of 43 and 71°C. There was very little evidence of metal buildup in the MMH or of any corrosion taking place. It is noted that this program was very limited.

VI. STRESS CORROSION IN MMH

Stress corrosion susceptibility was evaluated for several alloys in hydrazine-type fuels (Ref. 25). The evaluation was on the basis of crack growth in wedge opening loaded fracture specimens. The alloys tested are classified in order of decreasing susceptibility as follows: 4130 steel, 410 CRES, Inconel 718, 6Al-4V Ti, 6061-T6 Al. The aluminum alloys show no susceptibility. The order of decreasing stress corrosion cracking promotion for the fuels is hydrazine, MMH, UDMH. Crack growth susceptibility is related to contamination levels of water and carbon dioxide.

VII. CONCLUSIONS

Based upon the findings of the literature search covering MMH propellant compatibility with aluminum and corrosion-resistant steel alloys, the conclusions are:

1. The major uncertainty resides in the contaminant area relative to carbon dioxide and water content.

2. No compatibility data are available that either meet or are directly applicable to the survey requirements (Table 2) and materials of interest (Table 3).

3. Since no data are available on the conjoint effects of acidic contaminants, carbon dioxide and water, no predictions of the effects of these contaminants can be made with confidence.

4. Although few data are available, and most at the lower temperatures, it appears that, in general, monomethylhydrazine exhibits somewhat greater stability toward catalytic decomposition than does hydrazine propellant. It is also generally considered that metals which are compatible with hydrazine are compatible with monomethylhydrazine. Therefore, based upon similarity and comparison, it is not apparent that incompatibilities will be experienced with pure monomethylhydrazine and metals of interest up to a temperature of 43°C (110°F).

VIII. RECOMMENDATION

Based upon the results of this search, it is recommended that the experimental storage testing, Phase 2, with propellant and materials of interest (Tables 2, 3) be implemented as planned in order to acquire the proper design data.

Table 1. Chemical and Physical Properties of Monomethylhydrazine Propellant

Constituent or Property	MIL-P-27404A Amendment 2 Specification Limits
Monomethylhydrazine ($N_2H_3CH_3$) assay, % by weight	98.3 min
Water, % by weight	1.5 max
Particulate, milligram per liter	10.0 max
Density, grams per milliliter at 25°C (77°F)	0.870 to 0.874

Table 2. Monomethylhydrazine Propellant Survey Requirements

Item	Constituent, Property or Condition
Propellant	Baseline - specification grade MMH, Table 1
Contamination	
Carbon dioxide, CO_2	500-550 parts per million
Water, H_2O	3% by weight (replaces 1.5%, Table 1)
Temperature	Up to 71°C (160°F)

Table 3. Materials Considered for Compatibility Review

Material	Types	
	Available in Small Lot Quantities	Either Obsolete or Only Available in "Mill Run Lots"
Aluminum alloys	5052 5086 5456[a] 6061	5083 5154 5254 5454 5652
Corrosion-resistant steel alloys	316, 316L, 321, 430	

[a]Proposed as a substitute for 5454. Alloy more commonly used.

Table 4. Chemical Composition Limits of Materials[a]

Element / Type Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	C	P	S	Ni	Other
Aluminum Alloy per ASTM B209-74 (Ref. 4)														
5052	0.45	+Fe	0.10	0.10	2.2-2.8	0.15-0.35	0.10		Balance					0.15
5083	0.40	0.40	0.10	0.40-1.0	4.0-4.9	0.05-0.25	0.25	0.15	Balance					0.15
5086	0.40	0.50	0.10	0.20-0.7	3.5-4.5	0.05-0.25	0.25	0.15	Balance					0.15
5154	0.45	+Fe	0.10	0.10	3.1-3.9	0.15-0 35	0.20	0.20	Balance					0 15
5254	0.45	+Fe	0.05	0.01	3.1-3.9	0.15-0.35	0.20	0.05	Balance					0 15
5454	0.40	+Fe	0.10	0.50-1.0	2.4-3.0	0.05-0.20	0.25	0.20	Balance					0.15
5456	0.40	+Fe	0.10	0.50-1.0	4.7-5.5	0.05-0.20	0.25	0.20	Balance					0.15
5652	0.40	+Fe	0.04	0.01	2.2-2.8	0.15-0 35	0.10		Balance					0.15
6061	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0 04-0.35	0.25	0.15	Balance					0.15
Corrosion-Resistant Steel Alloys per ASTM A240-75a (Ref 5)														
304[b]	1 00	Balance		2.00		18.00-20.00				0.08	0.045	0.030	8.00-10 50	0.10
304L[b]	1 00	Balance		2.00		18.00-20.00				0.03	0.045	0.030	8.00-12.00	0.10
316	1.00	Balance		2.00		16.00-18.00				0.08	0.045	0.030	10.00-14.00	Mo 2.00-3.00
316L	1 00	Balance		2.00		16.00-18.00				0.03	0 045	0.030	10.00-14.00	Mo 2.00-3.00
321[b]	1.00	Balance		2.00		17.00-19.00				0.08	0.045	0.030	9.00-12.00	Ti 5xC min-0.70 max
347[b]	1.00	Balance		2.00		17.00-19.00				0.08	0.045	0.030	9.00-13.00	C_b+Ta 10xC min-1.10 max
430	1.00	Balance		1.00		16.00-18.00				0.12	0.040	0.030	0.75	
17-7[b,c]	1.00	Balance		1.00		18.00			1.50	0.09	0 040	0.030	7.75	

[a]Limits are in percent maximum.

[b]Included for information purposes.

[c]Specification MIL-S-25043 and/or AMS 5528A.

Table 5. Mechanical Property Limits of Materials

Material Alloy or Type	Temper[a,b,c]	Thickness,[c] mm	(in.)	Tensile Strength, MPa (KSI) Minimum	Tensile Strength, MPa (KSI) Maximum	Yield Strength, MPa (KSI) Minimum	Yield Strength, MPa (KSI) Maximum	Elongation Minimum, %
Aluminum Alloy per ASTM B 209-74 (Ref. 4)								
5052	O	1.29-2.87	(0.051-0.113)	172 (25.0)	214 (31.0)	66 (9.5)	-	19
5052	H34	1.29-2.87	(0.051-0.113)	234 (34.0)	283 (41.0)	179 (26.0)	-	6
5083	O	1.29-38.10	(0.051-1.50)	276 (40.0)	352 (51.0)	124 (18.0)	200 (29.0)	16
5083	H323	1.29-3.18	(0.051-0.125)	310 (45.0)	372 (54.0)	234 (34.0)	303 (44.0)	8
5086	O	1.29-6.32	(0.051-0.249)	241 (35.0)	303 (44.0)	97 (14.0)	-	18
5086	H32	1.29-6.32	(0.051-0.249)	276 (40.0)	324 (47.0)	193 (28.0)	-	8
5154	O	1.29-2.87	(0.051-0.113)	207 (30.0)	283 (41.0)	76 (11.0)	-	16
5154	H32	1.29-6.32	(0.051-0.249)	248 (36.0)	296 (43.0)	179 (26.0)	-	8
5254	O	1.29-2.87	(0.051-0.113)	207 (30.0)	283 (41.0)	76 (11.0)	-	16
5254	H32	1.29-6.32	(0.051-0.249)	248 (36.0)	296 (43.0)	179 (26.0)	-	8
5454	O	1.29-2.87	(0.051-0.113)	214 (31.0)	283 (41.0)	83 (12.0)	-	16
5454	H32	1.29-6.32	(0.051-0.249)	248 (36.0)	303 (44.0)	179 (26.0)	-	8
5456	O	1.29-38.10	(0.051-1.50)	290 (42.0)	365 (53.0)	131 (19.0)	207 (30.0)	16
5456	H323	1.29-3.18	(0.051-0.125)	331 (48.0)	400 (58.0)	248 (36.0)	317 (46.0)	6
5652	O	1.29-2.87	(0.051-0.113)	172 (25.0)	214 (31.0)	66 (9.5)	-	19
5652	H32	1.29-2.87	(0.051-0.113)	214 (31.0)	262 (38.0)	159 (23.0)	-	7
6061	O	0.53-3.25	(0.021-0.128)	-	152 (22.0)	-	83 (12.0)	16
6061	T6	0.53-6.32	(0.021-0.249)	290 (42.0)	-	241 (35.0)	-	10
Corrosion-Resistant Steel Alloys per ASTM A240-75a (Ref. 5)								
304[d]	Annealed	under 4.76	(under 0.188)	515 (75.0)	-	205 (30.0)	-	40
304L[d]	↓	↓	↓	485 70.0)	-	170 (25.0)	-	40
316	↓	↓	↓	515 (75.0)	-	205 (30.0)	-	40
316L	↓	↓	↓	485 (70.0)	-	170 (25.0)	-	40
321	↓	↓	↓	515 (75.0)	-	205 (30.0)	-	40
347	↓	↓	↓	515 (75.0)	-	205 (30.0)	-	40
430	↓	↓	↓	450 (65.0)	-	205 (30.0)	-	22
17-7[d,e]	Cond A	0.91-4.75	(0.036-0.187)	896 (130.0)	1034 (150.0)	282 (40.0)	379 (55.0)	20

[a]Aluminum alloy temper designations: annealed, O, intermediate, H; solution-treated and precipitation-treated, T.

[b]Aluminum alloy, temper O included for comparison purposes and background information relative to "Tank Car" materials and construction. The applicable specification (Ref. 2, par. 179 100-7) states "For fabrication, the parent metal may be O, H112, or H32 temper, but design calculations must be based upon minimum tensile strength O temper welded condition.

[c]Applicable to Phase 2 (Section IC1) test specimen: aluminum alloy temper H and T, sheet stock thickness 1.600 mm (0.063 in.)

[d]Included for information purposes.

[e]Specification MIL-S-25043 and/or AMS 5528A

[f]Elongation in 50.8 mm (2.0 in.) minimum.

Table 6. Summary of Properties of Monomethylhydrazine Propellant[6]

Chemical name: methylhydrazine

Chemical formula: $CH_3N_2H_3$

Formula weight: 46.0724

Property	Value
Freezing point	-52.37°C
Boiling point	87.65°C
Critical temperature	312°C
Critical pressure	81.3 atms
Critical density	0.29 g/cc
Density, liquid	0.8702 g/cc
Vapor pressure, 25°C	49.47 mm Hg
Surface tension, 25°C	33.83 dyne/cm
Viscosity, liquid, 25°C	0.775 cp
Heat of fusion	2.490 kcal/mole
Heat of vaporization, 25°C	9.648 kcal/mole
Heat capacity, liquid, 25°C	32.25 cal/mole-deg C
Heat capacity, gas, 25°C	17.0 cal/mole-deg C
Heat of formation, liquid, 25°C	13.106 kcal/mole
Heat of combustion, liquid	311.7 kcal/mole
Entropy, liquid, 25°C	39.66 cal/mole-deg K
Entropy, ideal gas, 25°C	72.02 cal/mole-deg K
Flash point	1.1°C

APPENDIX

Literature Search Details

The material in this appendix presents details of conducting the literature search as noted in Section IIA. This information is provided primarily for the purposes of identifying the literature that was associated with the subject of MMH propellant material compatibility and recording the list of such documents for possible data retrieval or dissemination to avoid duplication at a later date.

The details of the input, sources for material, and output are discussed in the next sections.

I. SURVEY INPUT

These terms delineated the descriptors, identifiers, and/or other key words or data.

A. Search Terms

The specific terms listed below were supplied to the JPL Technical Information and Documentation Division, and were applied to both the primary and alternate data base searches.

1. Period of interest: CY1960 to present.

2. Propellant

   Monomethylhydrazine propellant per MIL-P-27404A; MMH; Methylhydrazine, $CH_3N_2H_3$.

3. Materials

   Aluminum alloys - types 5052, 5083, 5086, 5154, 5254, 5456, 5652, 6061.

   Corrosion-resistant steels (CRES) - 304, 316, 316L, 321, 347, 430

4. Pertinent information

   Amine fuels

   Compatibility: short-term/long-term storage, 10 years

   Propellant decomposition

   Corrosion (material loss, pitting, scaling, cracking, stress)

   Temperature up to 160°F (200°F also acceptable)

   Rockets, ballistic missiles, spacecraft

Welded types

Weld rod materials

Storage containers

Shipping containers

Drums, tank cars, cargo vessels

Contaminants or impurities

Carbon dioxide

Water

Gel formations

Adduct formations

Residue formations

5. Specifications and/or regulations

   Specifications Department of Transportation

   (DOT) 5, 5A, 5C, 17E

   DOT Regulation 49 CFR 170-190
                  49 CFR 170.13

   ASTM B209-74

   ASTM A240-75a

   "AAR" Association of American Railroads

6. Alternate propellant

   Considered for supplemental data

   Hydrazine per MIL-P-26536B and C; Hz; N_2H_4

II. SOURCES OF INFORMATION

The sources used for obtaining information included:

A. National Aeronautics and Space Administration (NASA)

   1. NASA Data Bank

   2. NASA Scientific and Technical Information Agency

B. Defense Documentation Center (DDC)

C. Document and Information Centers

   1. National Technical Information Service (NTIS)

   2. Chemical Propulsion Information Agency (CPIA)

D. Open Literature

III. LITERATURE SEARCH - OUTPUT

The responses to the searches were in the form of machine printouts, abstracts, or bibliographies. The results presented in the text of this report were based upon the assessments drawn from the original source material (i.e., report or document). In some cases it was necessary to also review certain reports to determine applicability to the subject matter, since the material described in the return was either inadequate or vague.

The following lists summarize the document numbers identified as potential sources of information, and considered during this literature survey.

A. NASA Data Bank (NASA/RECON; NASA LOG Numbers)

1. JPL Machine Search MR6383A

67X82988	64X80963	67X16431	65X37231	66A18472	66N22485
66X85623	64X80895	67X15964	65X20653	66A16493	66N20827
67X16433	67X2[illegible]847	67X14239	65X17543	65A32503	66N19172
67X12742	67X238[illegible]4	67X14013	63X17026	65A32496	66N16455
66X35291	67X2379[illegible]	67X13698	63X16481	65A32496	66N16155
66X21753	67X23711	67X13114	63X16259	65A21263	66N12392
63X13333	67X23707	67X12746	63X15066	64A28469	65N31864
66N13088	67X23682	67X11725	63X14873	64A17830	65N31081
63X82899	67X23681	66X23952	63X14168	64A11436	65N28967
63X82772	67X23107	66X23882	63X13486	63A15388	65N26554
63X81120	67X23000	66X21601	63X12468	66N85650	65N19151
63X81081	67X22922	66X21025	63X1124[illegible]	66N81128	65N19096
67X83964	67X22389	66X18420	63X11176	65N83036	64N28947
67X82708	67X21933	66X17119	63X11000	65N81712	64N17412
67X82625	67X21452	66X16991	63X10560	67N38893	63N18949
67X80577	67X20538	66X16383	63X10358	67N38892	63N13605
66X84470	67X20451	66X16097	63X10352	67N32644	63N13444
66X84465	67X18518	66X15592	63X10171	67N32461	62N14194
66X83271	67X18423	66X13299	67A41602	67N32289	
66X81930	67X17594	66X12472	67A41601	67N26221	
65X85101	67X17378	66X10438	67A38841	67N25331	
64X80969	67X16849	65X37232	66A34432	66N26347	

2. JPL MR6383A-1

65X11881	67A33979	67X21621	66X18852	67N86891	66N38372
66X83425	67X82707	67X20860	66X18161	67N83872	66N23466
66X13300	66X84689	67X19908	65X20695	67N80109	66N16153
66X22770	66X81069	66X20591	65X14473	66N85875	65N27959
67A80394	65X85233	66X20528	67A14426	64N85232	

3. JPL MR6383B

72X76023	70X12551	74A33924	68N81826	68N22599	72N21494
72X74589	70X11848	73A32220	68N80876	68N12336	
71X73320	69X18834	70A40475	76N10717	75A40978	
71X73319	69X18729	73N71684	73N11082	75N21433	
68X85235	69X10964	70N96246	70N36511	74N31328	
68X85224	69X10904	69N74934	69X24077	72N26678	

4. JPL MR6383P

74B10087	70X71657	68X84369	69X13302	74N76953	68N22463
72B10635	70X71656	68X84002	69X12962	74N75508	68X17202
69B10062	70X70181	68X82820	69X11804	71N72129	68X17032
68B10323	68X89062	68X82208	69X10407	70N70910	68X14729
73X70074	68X87338	70X15809	68X20345	69N71077	68X10975
72X79322	68X87337	70X11355	68X16501	76N22300	76A31357
71X73062	68X87336	69X18218	68X12004	75N18348	72N30417
70X75712	68X86961	69X15939	68X11014	69N15511	
70X75472	68X86390	69X14745	76N73553	69N15134	

5. JPL MR6520

76X78265	75A39143	73N22712	68X88003	69X10898	68X11893
76X72176	75A39122	72N23804	68X86490	69X10877	68N86748
73X76511	73A27099	72N22764	68X85215	68X19958	68N34366
73X72847	75N70207	66B10586	68X85210	68X18649	
71X82256	74N74885	70X77398	69X17321	68X16901	
71X79641	76N30368	69X75422	69X16681	68X16371	
71X77926	74N17240	68X88008	69X16079	68X13058	

B. Defense Documentation Center (DDC; DDC LOG Numbers)

1. DDC Search Control No. 074881

AD-46311 368959 358160

2. DDC Search Control No. B47285

AD-905918L	507278L	463111	392353	358160
707109	502649L	392715	383391L	
507328L	500246L	392576	368959	

3. DDC Search Control No. 049813

AD-B013772L	905918L	833171L	505012	387820	379754
B008908L	901765L	823112L	502671	387028L	379510L
A022577	886250L	818021L	488587	385461	377624
A022434	886249L	817301L	393563	384237	377307
923542L	884840L	807276	392576	383999	376701
921469L	872299	801848	392576	383676	
915538	866010	755383	392575	382609L	
913714	854584	750900	292353	380444	
912666L	834269	506107	391551	380135	
909094L	833907L	506043	388940	379794	

C. Documentation and Information Centers

Chemical Propulsion Information Agency (CPIA); (Ref. 26).

LPIA 58,086A	AD371802	AD390470L	AD871792	N73-11788
LPIA 60,346	N67-17970	AD387317L	AD872299	N72-26878
L62-0200	AD379505	N67-35988	AD875615	AD736464
L62-0291	AD381201L	AD392353	CPIA 70-0869K	AD507864
X64-17491	X6817616	69-0062C	AD513541	AD771580
AD613553	AD379794	CPIA 69-0062E	AD884840L	AD919074
N65-35394	AD384548	CPIA 69-0343Z	AD888768L	N7430233
AD374597	AD380919L	AD679531	AD735288	N7513022
AD367100	AD382914	AD393059L	CPIA 72-0179	75-0054C
AD368796	AD385049L	AD506094L		75-0054D
AD372277	AD819962	N70-25255		

D. Open Literature (Surveyed)

Chemical Abstract, Register Number 60 - 34 - 4

Chemical Abstracts	Volume	Year
Collective Index	41-50	1947-1956
	51-55	1957-1961
	56-65	1962-1966
	66-76	1967-1971
General Subject Index	76	1972
	77	1972
	78	1973
	79	1973
	80	1974
	81	1974
	82	1975
	83	1975
	84	1976

DEFINITION OF TERMS

AAR	American Association of Railroads
AFRPL	Air Force Rocket Propulsion Laboratory (United States)
AIAA	American Institute of Aeronautics and Astronautics
Al	aluminum
ASTM	American Society for Testing and Materials
CPIA	Chemical Propulsion Information Agency
CRES	corrosion-resistant steel
DDC	Defense Document Center
DOD	Department of Defense (United States)
DOT	Department of Transportation
Hz	hydrazine
JANNAF	Joint Army-Navy-NASA-Air Force
JPL	Jet Propulsion Laboratory (California Institute of Technology)
LPIA	Liquid Propulsion Information Agency
MMH	monomethylhydrazine or methylhydrazine
NASA	National Aeronautics and Space Administration
NASA/RECON	NASA/remote console
ppm	parts per million
Ti	titanium
UDMH	unsymmetrical dimethylhydrazine or uns-dimethylhydrazine

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2. Hazardous Materials Regulations of the Department of Transportation Including Specifications for Shipping Containers, Supplement No. 1 to R. M. Graziano's Tariff No. 30, April 30, 1976.

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4. "American Society for Testing and Materials, Standard Specification for Aluminum-Alloy Sheet and Plate," ASTM Designation B 209-74, December 1974.

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6. "USAF Propellant Handbooks Hydrazine Fuels," Volume 1, AFRPL-TR-69-149, Bell Aerospace Company, Buffalo, New York, March 1970 (70X15809/AD-507864).

7. "Chemical Rocket/Propellant Hazards, Volume III, Liquid Propellant Handling, Storage, and Transportation," JANNAF Propulsion Committee, CPIA Publication No. 194, Chemical Propulsion Information Agency, Silver Spring, Maryland, July 1972 (77N71281/NASA-CR-111359/AD-870259L).

8. "Liquid Propellants Manual, Unit 11," LPIA-LPM-1, Liquid Propellant Information Agency, December 1961 (68X86390/NORD-7386).

9. Federal Register, Vol. 36, No. 157, August 13, 1971.

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12. "Aerospace Fluid Component Designers Handbook," Report AFRPL-TDR-64-25, Sec. 12.5, TRW Systems Group, Redondo Beach, California, February 1970 (AD-809182).

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